Plan of Study

Connecticut Hurricane Evacuation Study

FEDERAL EMERGENCY
MANAGEMENT AGENCY

US Army Corps
of Engineers
New England Division

FEBRUARY 1988

TABLE OF CONTENTS

APPENDIX C
LONG ISLAND SOUND SLOSH MODEL

APPENDIX D
PROJECT SCHEDULE AND LOGIC NETWORK

LIST OF TABLES

FIGURES

I. INTRODUCTION

STUDY AUTHORITY

This Hurricane Evacuation Study is being conducted by the Corps of Engineers, New England Division at the request of the State of Connecticut. This investigation is part of a National, co-sponsored effort between the Corps of Engineers and the Federal Emergency Management Agency (FEMA). FEMA is delegated primary authority through Executive Order 12148 (P.L. 93-288). FEMA will function as the program manager for this investigation and will provide partial funding under the Authority of the Flood Plain Management Service (FPMS) Program (Section 206 of the 1960 Flood Control Act as amended).

STUDY PURPOSE

The purpose of this investigation is to identify the areas and population within the State of Connecticut vulnerable to the effects of a potential hurricane landfall, and to estimate the time and conditions required to safely evacuate the study area.

The infrequency of hurricane landfalls along the northeast United States coastline has created a complacent attitude among coastal populations toward their danger from hurricanes. This casual attitude combined with the rapid population growth of the coastal areas has strained the ability of some state, county and local governments to adequately respond to the threat of a hurricane. Population growth in some areas has increased the required evacuation time beyond the 12 to 16 hours of warning time which the National Hurricane Center (NHC) believes it can confidently provide. The course of a hurricane, its landfall point, and its intensity are difficult to predict. Emergency response plans for the evacuation and shelter of vulnerable populations must be developed which account for all potential hurricane variables.

STUDY SCOPE

The Connecticut Hurricane Evacuation study will be conducted in two phases. Phase I will comprise the development of a technical document which will address the hazard, vulnerability, behavioral, shelter and transportation analyses. Each of these topics is outlined in detail in Section II of this report. The Corps of Engineers, New England Division will have the primary responsibility for the completion of this report. State and local agencies will receive interim products throughout this phase for their review and input.

Phase II shall comprise the development of local guides and public awareness information. Local agencies will have the primary role under this phase of the study with assistance provided by the New England Division.

STUDY OBJECTIVE

The objective of the hurricane evacuation study is to provide a technical assistance report from which the state, counties and municipalities can update or refine their existing response plans or formulate new ones. The study will be a comprehensive effort focusing on the entire state's response to the threat of a hurricane. The evacuation study will identify areas along the Connecticut coast vulnerable to hurricanes of various intensities, direction and forward speed. The investigation will determine, for several scenarios, the population at risk, how they would respond to an evacuation order, and how much time would be required to safely evacuate the vulnerable areas.

The study will be designed to encourage cooperative efforts between local emergency preparedness elements and their state counterparts, and will attempt to enhance the utilization of the information and advisories provided by the National Hurricane Center.

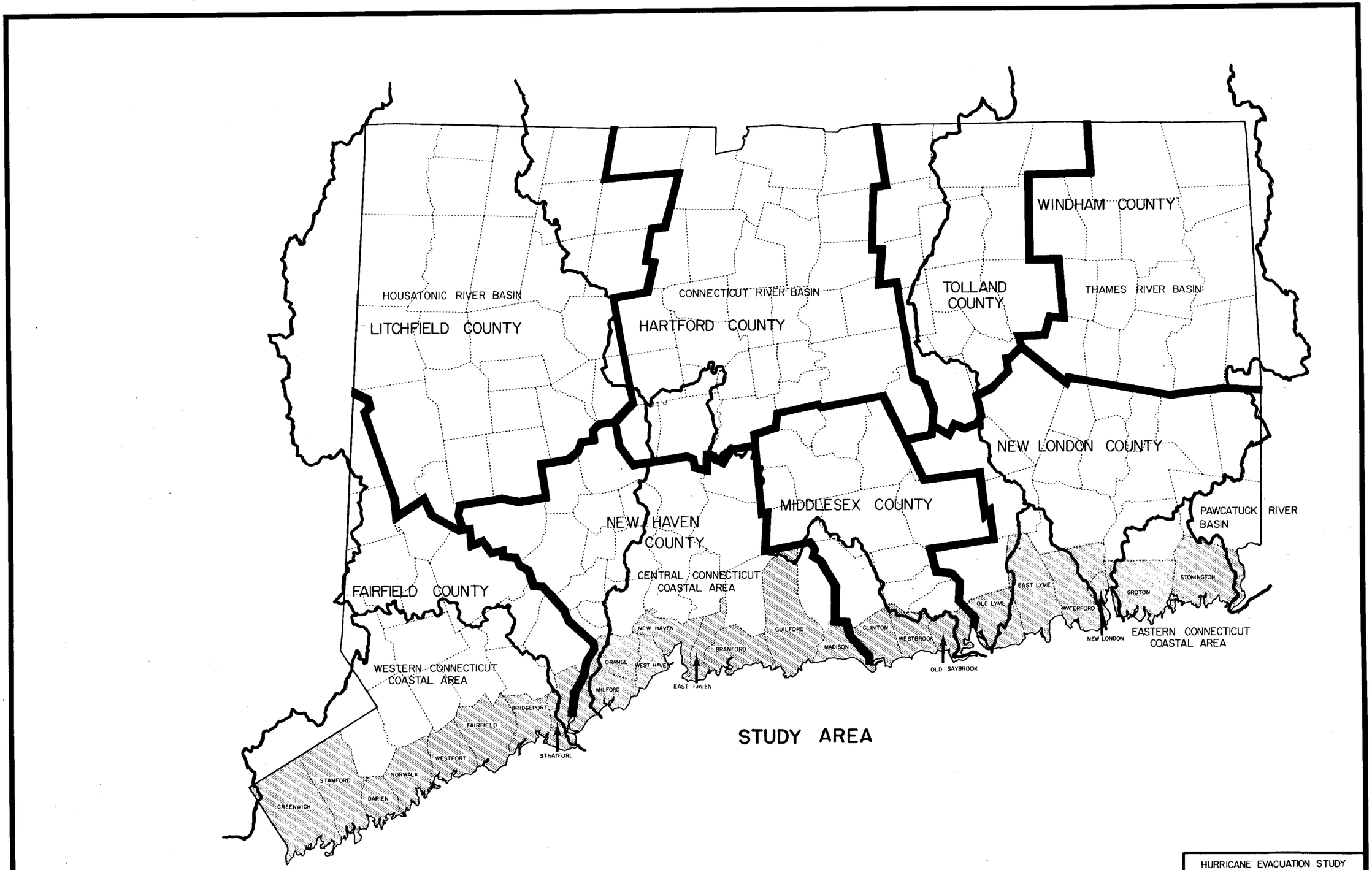
STUDY AREA

The study area for this investigation consists of the portions of the Connecticut counties which border either the Long Island Sound, Block Island Sound, and one or more of the low lying river systems. These counties include New London, Middlesex, New Haven and Fairfield. A location map of the study area is shown on Figure 1.

STUDY MANAGEMENT AND COORDINATION

The management of the Connecticut Hurricane Evacuation study will be accomplished by the Corps of Engineers, New England Division. The work effort will be divided into two phases. Phase I will involve the completion of a Technical data report by the Corps of Engineers. Phase II will consist of the preparation of implementation guides and public information material. This will be accomplished by the State or local civil preparedness organizations, with assistance from FEMA and the Corps.

The Corps of Engineers will maintain coordination with all interested Federal, state and local agencies throughout the study. Overall guidance will be maintained through two study coordination groups consisting of an Executive Planning Committee and a Technical Advisory Committee which will be established by FEMA, with the assistance of the Corps and the State of Connecticut. The Executive Planning Committee will consist of representatives from the Corps, FEMA and appropriate state agencies needed to insure adequate interjurisdictional coordination. This committee will provide comments and recommendations concerning the conduct of the study. The Technical Advisory Committee will be comprised of, but not limited to, individuals from agencies or organizations with emergency management responsibilities in the event of a hurricane threat. This committee will review study tasks, generated data, the use of the data in the formulation of response plans, and will support the overall task of developing the technical data report. All meetings of each committee will be documented and study progress reports will be prepared by the Corps and provided to committee members. Meetings of each group will be scheduled by FEMA and the Corps.



HURRICANE EVACUATION STUDY
STATE OF CONNECTICUT

STUDY AREA

SEPTEMBER 1987

FIGURE 1

II. PHASE I - STUDY DESCRIPTION

Phase I of this investigation will identify the areas of population in the State of Connecticut at risk from a potential hurricane and will determine the time and actions required to safely evacuate the endangered population. This phase of the investigation will conclude with a Technical Data Report which will document each aspect of this investigation.

The Corps of Engineers and FEMA, through numerous Hurricane Evacuation Studies along the Gulf and Atlantic coastlines, have developed a general study methodology for all hurricane evacuation studies. The study methodology addressed each critical element required to develop a hurricane preparedness plan. These guidelines have been modified for the Connecticut study area and will be used for this investigation. The following presents an outline and explanation of each element of the study. An outline of the study's logic network is provided in Appendix D.

HAZARD ANALYSIS

The hazard analysis will identify the Connecticut coastal areas and inland riverine areas which could be inundated from a hurricane storm surge. The National Hurricane Center is developing a SLOSH (Sea, Lake, and Overland Surge from Hurricanes) numerical model to predict the impact to the shoreline from simulated hurricanes of determined intensity, direction and forward speed. Hypothetical storms with intensities of 1-4 on the Saffir/Simpson scale (Appendix B), storm directions ranging from WNW to NE, and forward speeds of 20, 40 and 60 miles per hour (MPH). The results of each storm will be analyzed and combined with similar results to produce a manageable number of synthetic storms. Preliminary profiles and inundation maps will be prepared for each composite storm to determine initial evacuation zones. The results of this analysis will be used in conjunction with transportation models and population and behavioral survey data to calculate the time required to evacuate the areas at risk.

VULNERABILITY ANALYSIS

The vulnerability analysis will include a comprehensive evaluation of each hazard area identified by the SLOSH model analysis. The vulnerability analysis will include the development of evacuation zones, the identification of pre-landfall factors which could effect an orderly evacuation, the population within each evacuation zone, a shelter evaluation, and the identification of any special considerations. The vulnerability analysis will be divided into the following tasks.

Evacuation Zones - The results of the SLOSH model will provide an inundation map of hurricane storm surge for the entire State of Connecticut. The inundated portions of the State will be divided into smaller evacuation zones. The division of the State will be

determined by state and local civil preparedness agencies and should conform to existing jurisdictions. The various evacuation zones will be expanded utilizing Traffic Analysis Zones, census tracts or other local designations to facilitate future updating of the plan. Final delineations should conform as much as possible to easily recognize geographic features.

Pre-landfall Hazard Study - Each of the evacuation zones will be studied to identify pre-landfall hazards which could restrict or impede implemented hurricane response plans. Some of the factors to be considered are pre-landfall storm surge, inland flooding due to rainfall, high winds and roadway erosion due to wave action.

Flooding of roadways from rainfall preceding the storm or from storm surge from an advancing storm could inundate roadways vital to evacuation. Existing flood insurance maps will be used to evaluate rainfall flooding hazards. The selected Time/History data from the SLOSH model will be used for the pre-landfall surge analysis.

Wave action on coastal roadways can cause erosion to the pavement surface and subsurface resulting in the loss of potential evacuation routes. Wave runup analyses will be performed on areas which appear vulnerable to wave induced erosion.

The most critical pre-landfall hazard which must be determined is the arrival of gale-force winds prior to the storm landfall. This is the most significant hazard related to the timing of an evacuation order. The evacuation of the population should be completed prior to the arrival of gale-force winds. The arrival of gale-force winds will be determined from the SLOSH Time/History data on computed wind speeds.

Population Study - The entire population-at-risk shall be enumerated for each evacuation zone utilizing the best available source of information. The data shall include both seasonal and permanent populations, number and types of dwellings and the number of vehicles within the threatened area. The number of mobile home residents, whether or not subject to storm threat, shall also be determined.

Institution Study - The hurricane evacuation study will address the problems associated with developing response plans for medical facilities, nursing homes, detention centers, schools and other institutional facilities which would require special consideration. The analysis will include inventories of each type of institution within each evacuation zone and a determination of its storm surge susceptibility. This information will be cataloged and provided as part of the technical data report.

Emergency Transportation Needs - The transportation needs of the elderly, disabled, and others unable to vacate will be addressed along with the transportation needs required to evacuate the identified institutions. Allowances will also be made for motorists who become stranded on roadways. This analysis will be closely coordinated with appropriate state and local agencies.

Shelter Analysis - The shelter analysis shall include inventories, capacity evaluations and storm surge analysis of existing local public shelters, projected additional shelter needs, and shelter duration analysis for the various local and regional evacuation scenarios. Existing shelter evaluations shall include inventories, locations, capacities, and surge analysis of the region. Much of the information will be obtained from the local emergency management agencies or other agencies having a responsibility for shelter designation and management. The results of the surge analysis shall be utilized to determine the suitability of existing shelters and resultant capacities under the various evacuation scenarios.

The results of the population-at-risk and behavioral analyses shall be utilized to determine the needs for additional public shelters. Final determination of additional shelter needs and assignment of shelter destinations to the various evacuation zones will be made during the transportation analysis phase of the study. Minimum shelter duration for the various evacuation scenarios of the region shall be predicted using the SLOSH model's time histories of computed wind speeds.

BEHAVIORAL STUDY

The purpose of the behavioral study is to develop reliable data concerning the expected response of the affected and the non-affected population under various hurricane threats. The analysis will determine the following:

1. When the threatened population will evacuate their homes in relation to a given order.

2. The number of vehicles the threatened households would utilize for evacuation, including towed vehicles.

3. The number of threatened households that would require transportation or other assistance.

4. The pre-planned destination of the potentially threatened population.

5. The relationship of forecasted intensity to population response.

6. The response of tourists to hurricane threats.

The behavioral analysis shall be conducted utilizing available behavioral data from historic hurricanes in the region, coordination with local and state emergency management agencies and the results of other behavioral data surveys as appropriate.

Comparisons of behavioral data compiled to date for independent hurricane evacuation studies indicate significant variations in response from one geographic area to another for similar hurricane

threats generally do not occur. Sampling will be conducted to test the applicability of existing behavioral data from other geographic locations. The response data will be used in shelter planning, transportation modeling, emergency decision making, and public awareness efforts.

TRANSPORTATION STUDY

The purpose of the transportation study is to identify the evacuation roadway network and estimate the time required to evacuate each zone under various hurricane scenarios. The transportation analysis will utilize the information developed in the vulnerability analysis and behavioral study in a computer model to develop the evacuation times.

CLEARANCE TIMES

Using the transportation model and other analyses, the vehicle travel times will be calculated in hours for evacuating vehicles to reach their desired shelter destinations. The clearance time estimates shall consist of mobilization time, travel time, and queuing delay time. These estimates will consider the reductions in roadway capacities based on ambient weather conditions and traffic conditions, modifications to roadway networks to improve clearance times utilizing known traffic control points, internal travel by those not evacuating, and the timing of public response to ordered evacuations.

EVACUATION TIMES

Preliminary evacuation order time shall be determined for each county in the region and for each local and regional evacuation scenario. A range of evacuation order times shall be determined by adding the varying pre-landfall hazard times and evacuation clearance times. The development of evacuation order times shall be coordinated with local civil defense and other appropriate committee representatives and finalized under Phase II.

TECHNICAL DATA REPORT

Technical data studies will begin during coordination of the hazards analysis. Interim products of the various analyses such as identification of vulnerable areas and evacuation zones, and the result of the shelter analyses will be coordinated with state and local agencies and submitted for their review during Phase I as each analysis is completed. All interim products will be reviewed by the Technical Advisory Committee and are subject to the approval by FEMA. The final Technical Data Report will contain all of the interim products. It will include all maps, charts, graphs, tables, and appendices necessary to detail the significant factors affecting hurricane evacuation in the State of Connecticut.

III. PHASE II STUDY DESCRIPTION

LOCAL IMPLEMENTATION

The planning effort that will be undertaken in Phase I will provide officials in the State of Connecticut with quantitative data on which evacuation decisions can be based. Under Phase II of the study effort, FEMA and the Corps of Engineers will assist local civil defense/disaster preparedness officials to produce Implementation Reports or Guides for each county. These documents will include information from the Technical Data Report of Phase I which is specific to a given county and which can be used as an additional tool in making evacuation decisions.

IMPLEMENTATION GUIDES

These guides are intended to provide an orderly system for the timely evacuation of those citizens and visitors determined to be residing in high risk areas when their lives or safety are imperiled as a catastrophic consequence of a hurricane. The guides will assign responsibility and establish procedures for the coordinated efforts of government and volunteer agencies necessary to execute an evacuation upon receipt of such an order. Information on the communication of evacuation orders will be detailed such as who has the authority to order an evacuation and how that order will be communicated. State ability to enforce maintenance of evacuation plans will also be addressed. The format and content of the implementation guides shall be decided by officials in the State of Connecticut and its local communities. The guide shall furnish concise information and instructions to assist local state civil defense and other emergency management organizations concerning:

1. The level of expected threat.
2. The area threatened.
3. The population-at-risk under the threat.
4. The facilities available to support public sheltering.
5. The transportation routes available for evacuation.
6. The timeframe available in which to conduct a safe evacuation.
7. Communication of evacuation orders.
8. Interstate agreements of coordinating mechanisms concerning evacuation routes, sheltering, etc.
9. State government ability to enforce local government maintenance of evacuation plans.

Supporting the implementation guides shall be county and region-wide maps that identify evacuation routes, locations of traffic control points and shelter locations. These maps will be provided to county and state emergency management organizations as reference tools for the implementation guides.

PUBLIC INFORMATION MATERIALS

Public information materials may consist of tabloids for dissemination at the beginning of a hurricane season and scripts, maps, or video display materials for radio and television as appropriate during a hurricane emergency.

TESTING OF PLAN

The Corps of Engineers shall monitor a region-wide hurricane evacuation exercise designed to test all major elements of the Connecticut Hurricane Evacuation Study. This effort will be coordinated through FEMA. The exercise should test the capability of the state and each community to identify the evacuation scenario it is being confronted with, as well as the apparent scenarios confronting neighboring jurisdictions. Response by the state and counties during the exercise will be simulated in the areas of communications, public warning, manpower/equipment deployment, resources allocation, timing of evacuation orders, shelter activation, emergency transportation and traffic control.

POST-EXERCISE CRITIQUE

Meetings shall be conducted with all participants following the hurricane evacuation exercise to evaluate the plan's capability to implement a sage and effective evacuation. A critique report shall be prepared as directed by FEMA that documents the exercise and critique session proceedings, recommends any plan revisions, and identifies areas where future evaluations or training may be necessary.

PROPERTY VULNERABILITY ANALYSIS (OPTIONAL ANALYSIS)

A property vulnerability analysis will be included in the Connecticut Hurricane Evacuation Study if sufficient funds are available from the study sponsors: FEMA, the Philadelphia District, and the State of Connecticut. At a minimum, the analysis shall determine the fiscal losses that may occur in the study area from the various hurricanes modeled. The primary focus of the analysis will center on identifying losses resulting from damage to privately and publicly owned structures. The scope and methods to be employed in the property vulnerability analysis shall be negotiated between FEMA and the Corps of Engineers prior to Phase II.

IV. CONCLUSION

The results of the Connecticut Hurricane Evacuation Study will be documented in a Technical Data Report, implementation guides, and public information brochures or tabloids. The technical data report will cover in detail the major analyses conducted as part of this study, identify the types and magnitudes of activities that will be carried out to prevent a large scale loss-of-life and provide sufficient information to enable local and state governments to draft specific operating procedures for temporary relocation of vulnerable populations.

Local implementation guides will be developed from data and information in the Technical Data Report. The guides will be simplified decision-making tools which allow emergency management agencies to more accurately determine the vulnerable areas populations under various hurricane threats; estimate public shelter utilization; establish communications procedures; and determine the time required to safely evacuate the threatened population for a wide range of storm conditions.

Public information brochures or tabloids will inform the general population of the specific hurricane preparedness instructions and their specific roles (i.e., relative vulnerability and assigned evacuation zones, routes and shelters) under the hurricane evacuation plan developed. In addition, local officials will be encouraged to develop audio/visual emergency public information material for use during actual hurricane evacuation conditions.

Finally, State and local officials will be encouraged to give support to local emergency management officials in their endeavors to improve emergency response effectiveness. Their support will help determine the success of future planning efforts

Hurricane Evacuation Study
State of Connecticut

APPENDIX A

CORRESPONDENCE

Department of the Army
New England Division, Corps of Engineers
Waltham, Massachusetts
February 1988

WILLIAM A. O'NEILL
GOVERNOR

STATE OF CONNECTICUT
EXECUTIVE CHAMBERS
HARTFORD, CONNECTICUT

BETTER YET CONNECTICUT

November 14, 1986

Mr. Henry G. Vickers
Regional Director
FEMA Region I
John W. McCormack POCH
Boston, Massachusetts 02109

Dear Mr. Vickers:

As the result of a meeting held on October 10, 1986, between representatives of the State of Connecticut, FEMA and United States Army Corps of Engineers, I am hereby requesting that FEMA, in cooperation with the Corps of Engineers, initiate a Hurricane Preparedness Study for the State of Connecticut. I understand that development of this study requires no commitment of funds by the State of Connecticut, but that certain aspects of the study may be expanded in scope at the state's request at a later date with the additional work funded by the state.

It is important to note that systems developed under the Hurricane Preparedness Study will not address the possible effects of extra-tropical storms which cause considerable damage along the Connecticut coastline. Accordingly, I am requesting a cost estimate for the development of a numerical storm surge model for extra-tropical storms. Only an estimate for such a project is being requested at this time.

The State of Connecticut looks forward to participating in this very important program.

Sincerely,

WILLIAM A. O'NEILL
Governor

WILLIAM A. O'NEILL
GOVERNOR

STATE OF CONNECTICUT
EXECUTIVE CHAMBERS
HARTFORD, CONNECTICUT

BETTER YET CONNECTICUT

December 1, 1986

Colonel Thomas A. Rhen
Commander
U.S. Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, Massachusetts 02254

Dear Colonel Rhen:

As the result of a meeting held on October 10, 1986, between representatives of the State of Connecticut, FEMA and U.S. Army Corps of Engineers, I am hereby requesting that the Corps of Engineers, in cooperation with FEMA, initiate a Hurricane Preparedness Study for the State of Connecticut. I understand that development of this study requires no commitment of funds by the State of Connecticut, but that certain aspects of the study may be expanded in scope at the state's request at a later date with the additional work funded by the state.

The State of Connecticut looks forward to participating in this very important program.

Sincerely,

WILLIAM A. O'NEILL
Governor

Hurricane Evacuation Study
State of Connecticut

APPENDIX B

THE SAFFIR/SIMPSON HURRICANE SCALE

Department of the Army
New England Division, Corps of Engineers
Waltham, Massachusetts
February 1988

THE SAFFIR/SIMPSON HURRICANE SCALE

The Saffir/Simpson Hurricane Scale is used by the National Weather Service to give public safety officials a continuing assessment of the potential for wind and storm-surge damage from a hurricane in progress. Scale numbers are made available to public-safety officials when a hurricane is within 72 hours of landfall. Scale assessments are revised regularly as new observations are made, and public-safety organizations are kept informed of new estimates of the hurricane's disaster potential.

Scale numbers range from 1 to 5. Scale 5 has been eliminated from this analysis as suggested by the National Hurricane Center, due to the extremely low probability of a hurricane of this magnitude ever landing as far north as the State of New Jersey. Scale No. 1 begins with hurricanes in which the maximum sustained winds are at least 74 miles per hour, while Scale No. 4 applies to those in which the maximum sustained winds are 155 miles per hour.

The scale was developed by Herbert Saffir, Dade County, Florida, consulting engineer, and Dr. Robert H. Simpson, former National Hurricane Center Director, and projects scale assessment categories as follows:

Category No. 1 - Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, and unanchored mobile homes. No real damage to other structures. Some damage to poorly-constructed signs. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.

Category No. 2 - Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Serious flooding at coast and many smaller structures near coast destroyed; large structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water three to five hours before hurricane center arrives.

Category No. 3 - Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly-constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Serious flooding at coast and many smaller structures near coast destroyed; large structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water three to five hours before hurricane center arrives.

Category No. 4 - Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows, and doors. Complete failure of roofs on many

small residences. Complete destruction of mobile homes. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water three to five hours before hurricane center arrives. Major erosion of beaches.

Category No. 5 - Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Low-lying escape routes inland cut by rising waters three to five hours before hurricane center arrives.

Dr. Neil Frank, former National Hurricane Center Director, has adapted atmospheric pressure ranges to the Saffir/Simpson Scale. These pressure ranges, along with a numerical break-down or wind ranges, are listed below:

NUMBER	MILLIBARS	INCHES	(MPH)	DAMAGE
1	980	28.94	74-95	Minimal
2	965-964	28.5-28.91	96-110	Moderate
3	964-965	7.91-28.47	111-130	Extensive
4	920-944	27.17-27.88	131-155	Extreme
5	<920	<27.17	155+	Catastrophic

Hurricane Evacuation Study
State of Connecticut

APPENDIX C

SLOSH MODEL

Department of the Army
New England Division, Corps of Engineers
Waltham, Massachusetts
February 1988

APPENDIX C
SLOSH MODEL

INTRODUCTION

The SLOSH (Sea, Lake and Overland Surges from Hurricanes) computer program is a numerical computer model, developed by the NWS, designed to forecast the abnormal rise in water level caused by the wind and pressure forces of a hurricane. This rise in the water surface which accompanies a hurricane is referred to as the storm surge. The SLOSH model computes the storm surge over water and along the coastline and extends the computations inland over the coastal flood plain. The results of the model can be utilized along with topographic information to determine the hurricane inundation zone.

A five-year program to adapt the SLOSH model to 22 geographic areas, or basins, along the Gulf Coast and the Atlantic coast began in 1981. The basins, shown in Figure 1, were developed roughly in their order of vulnerability to hurricane storm surges.

Although other models and methods have been used, the SLOSH model is considered to be the most sophisticated and appropriate for the hurricane evacuation studies. Other models have yielded reliable surge heights at the coastline, but are restricted to the open ocean environment. The SLOSH model has been designed to route the simulated hurricane storm surges into bays, estuaries, and coastal rivers. The model also has the capability of calculating storm surges over land masses such as islands, barriers and over the coastal terrain until the surge height is negated by the topography. This complexity in the mathematical model produces a more accurate and realistic simulation of the impact an area can expect from potential hurricanes.

THE MODEL

The SLOSH model consists of a set of equations which govern the change in the height of the water surface. These equations are derived from the Newtonian equations of motion and the continuity equation, applied to a rotating fluid with a free surface. The equations are vertically integrated from the sea bottom to the sea surface. This results in a quasi one layer model with a free-surface upper boundary, the sea surface, and a rigid lower boundary, the solid earth. Since the purpose of the model is to provide estimates of the flood

potential at the coast and inland, the coastline, which is a physical boundary, is placed in the interior of the model domain. The equations of motion are numerically solved along with a finite amplitude term, which is retained for the inland flooding calculations. An explicit finite difference scheme is used to numerically solve the equations on a computer.

The SLOSH model computes water heights over a geographical area covered by a network of grid points. This network, or model domain, is called a basin. The grid system is telescoping and polar, and contains over 5000 grid points located on lines extending radially outward, varying from 0.5 miles near the pole to 5.0 miles farthest from the pole. This variation in spacing results in fewer grid points over deep water and a higher density grid over land where the surge heights are of more interest. The model is tailored to each individual basin by using bathymetric and topographic map data to assign a water depth or terrain height to each grid point.

The SLOSH model can allow for the overtopping of barriers or the impeding of the flow of water. The model can determine the impact of barriers of significant size in relation to the host grid square. Types of barriers which are typically included in the SLOSH analysis include dunes, levees, spoil areas, natural ridges, reefs and various man-made structures. The model can also address sub-grid size cuts associated with river channels and between barriers. As the hypothetical storm approaches, the barrier restricts flow until the surge height exceeds the assigned height of the restriction. Once the restriction is overtopped, the computer activates the grid squares behind the barrier and commences calculating the storm surge. Conversely, as the storm surge recedes, the computer will terminate calculations in these squares once the surge height falls below the barrier height.

The SLOSH model is also equipped with a hurricane wind model. The input parameters for each run include the position (latitude and longitude), central pressure and storm size (distance from storm center top radius of maximum winds). These parameters are entered at six-hour intervals starting 48 hours prior to landfall and ending 24 hours after landfall. No information is entered regarding the hurricane winds. The internal SLOSH wind model produces a vector wind field throughout the basin by balancing the forces according to meteorological input parameters.

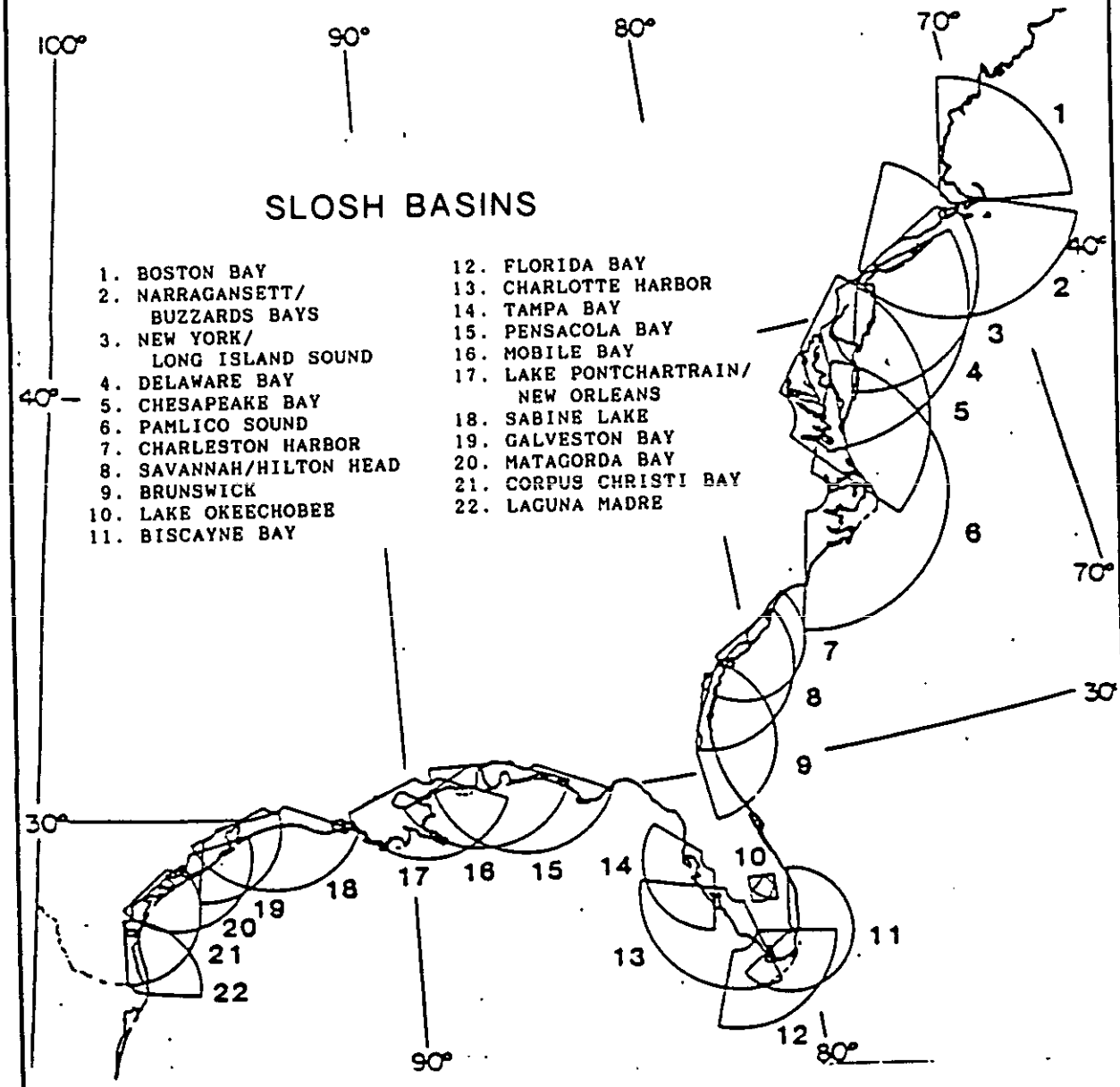
MODEL ACCURACY

The accuracy of the SLOSH model has been evaluated using approximately 540 surge observations from historical hurricanes. The SLOSH model is programed to approximate, as accurately as possible, the precise track of a historical event. The computed surge values are then compared to the corresponding observations to determine how well the model performed relative to the actual storm. The surge observations were obtained from tide gage information, staff records and high water marks. These observations were taken throughout the area affected by the surge, at the periphery and along the inland water bodies. A statistical analysis of the observed data vs. the calculated surge values determined an error range of + 20 percent for the significant surges with a few observations falling outside the boundary. Figure 2 shows a graph of the Observed Surge Heights vs. the Forecast Surge Heights.

CONNECTICUT STUDY

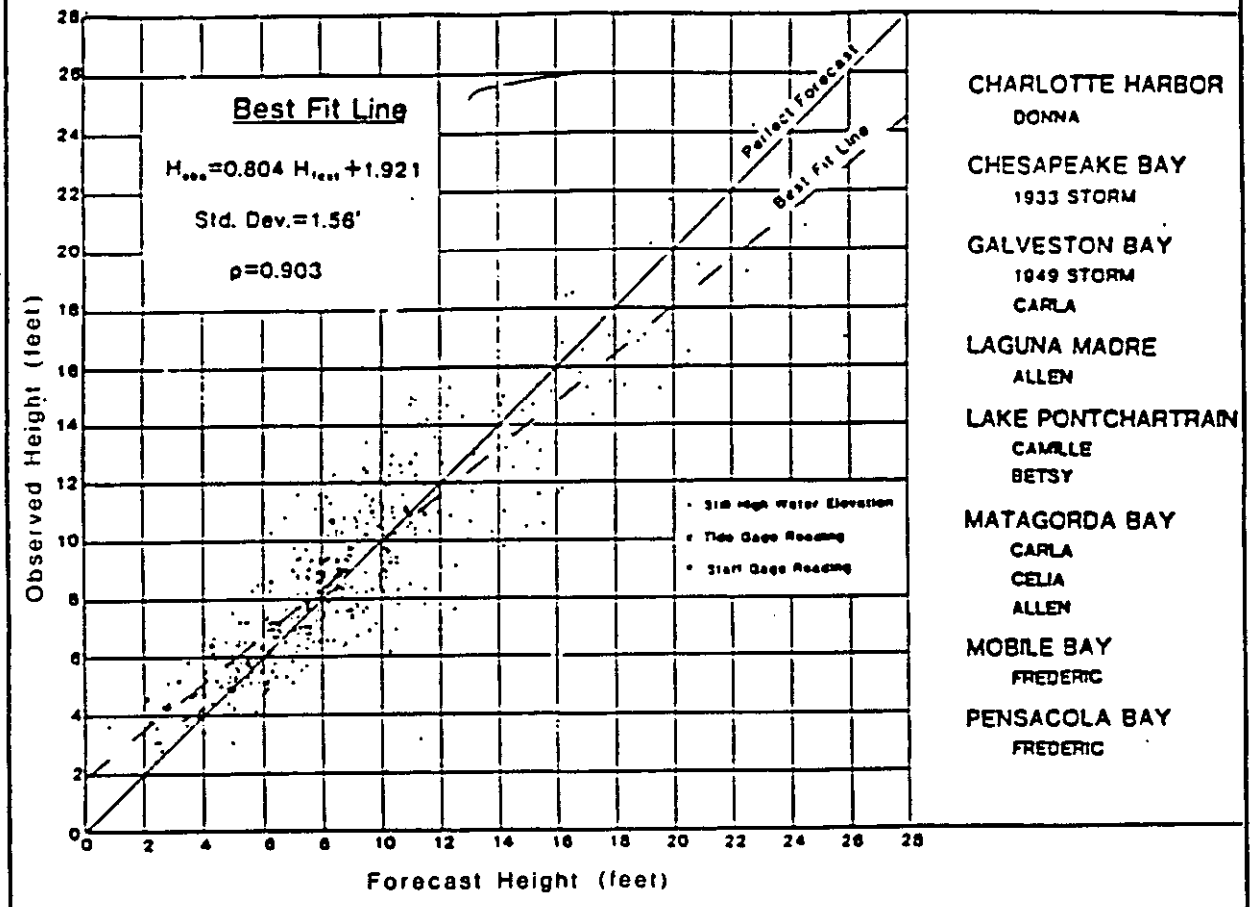
The hurricane surge data for the Connecticut Evacuation Study is based on the SLOSH model for the Long Island Sound basin. This basin encompasses the coastlines of New York, Connecticut and a small portion of New Jersey. The basin data was completed in 1985 and was calibrated using Hurricane Gloria and other historical information. The pole of the grid system is located in the area of New York City. The grid resolution for the Connecticut study area is larger than the New York area, but still yields satisfactory results. A view of the Long Island Sound Basin with an overlay of the grid system is shown on Figure 3. An overview of the Long Island Sound grid system applied to the Connecticut study area is shown in Figure 4.

Simulated storms varying in intensity, direction of movement, forward speed, and landfall location were selected for the Long Island Sound Model. The storm parameters were selected by the National Hurricane Center (NHC) based on historical information and their assessment of the meteorological climate in this region of the country. The NHC selected six (6) possible storm directions ranging from NE (N45E) to WNW (N67.5W) at an interval of 22.5 degrees. Each of the storm tracks were run with hurricane intensities ranging from Category 1 to Category 4, based on the Saffir/Simpson scale, and forward speeds of 20, 40 and 60 mph. This provided a matrix of potential hurricane threats to the Long Island Sound area. Several combinations of the selected storm parameters were not considered in the analysis. In the opinion of the NHC, storms moving with a strong westerly component would only result when influenced by a strong blocking front. This would eliminate the



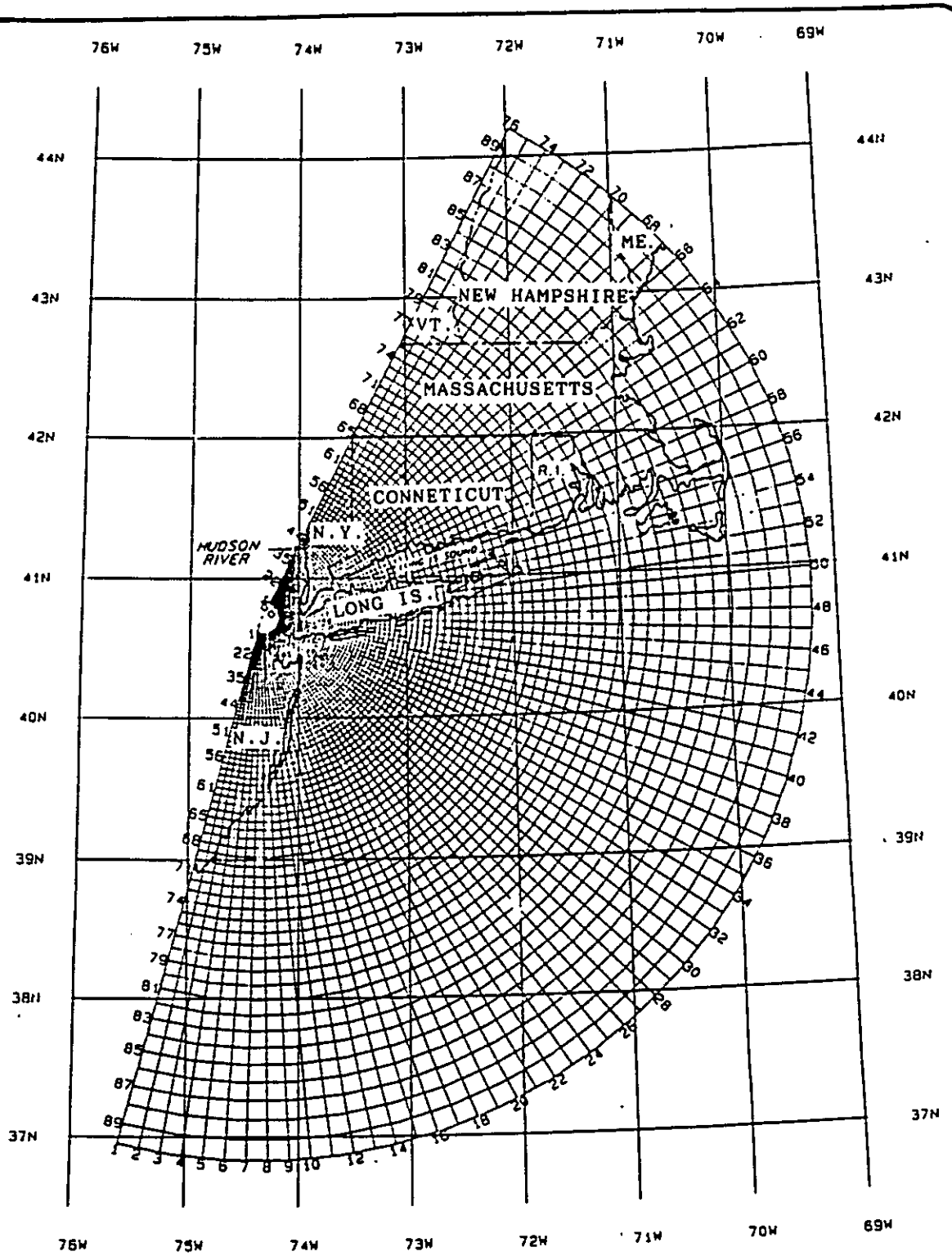
NATIONAL HURRICANE CENTER
SLOSH BASINS

FIGURE C-1



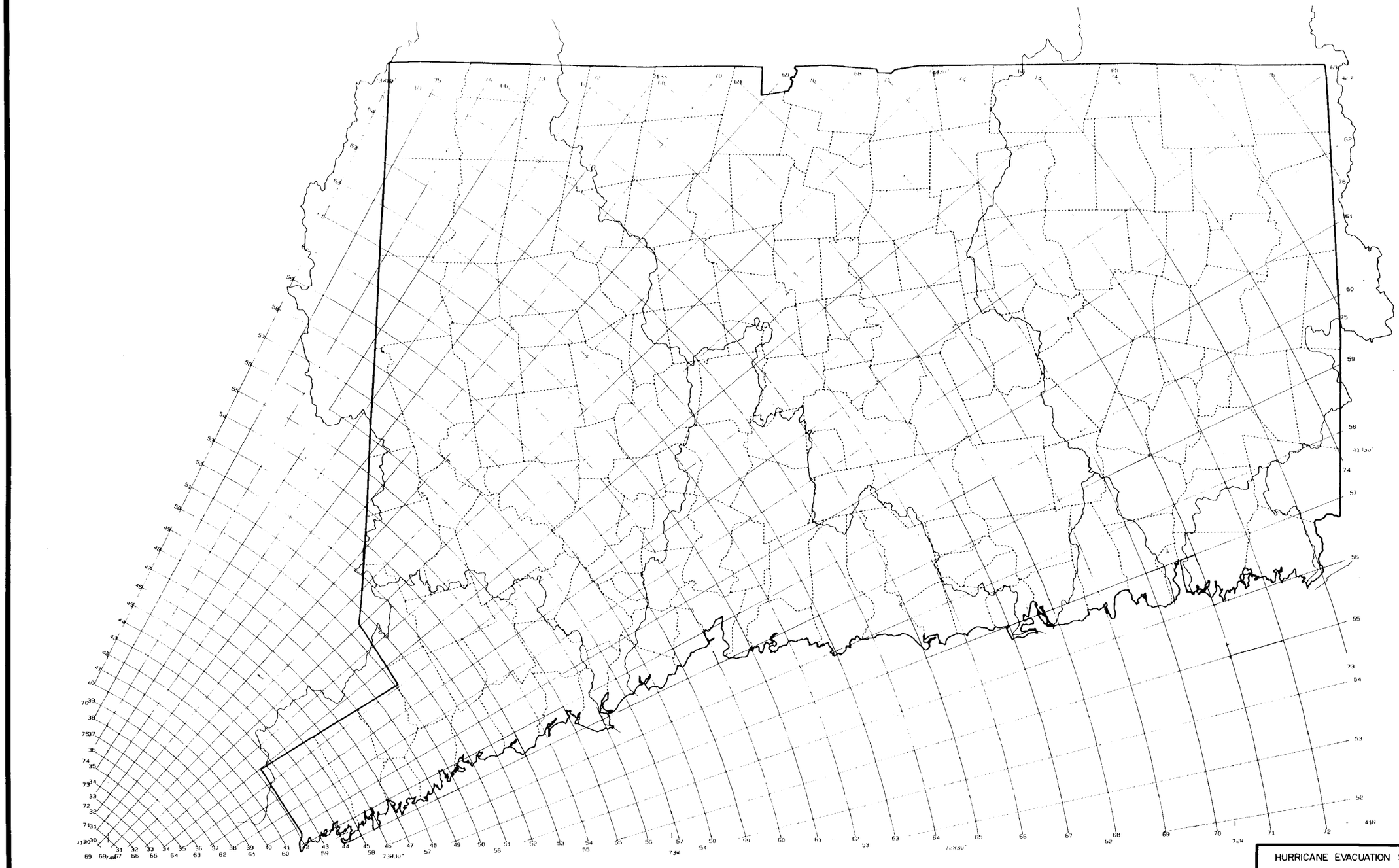
OBSERVED SURGE HEIGHTS VS. FORECAST SURGE HEIGHTS

FIGURE C-2



LONG ISLAND SOUND SLOSH BASIN

FIGURE C-3



HURRICANE EVACUATION STUDY
STATE OF CONNECTICUT

STUDY AREA

SEPTEMBER 1987

FIGURE C-4

Climatological conditions required for a fast moving storm, such as the 1938 event, moving on a westerly vector. To account for this condition, the NHC only simulated westerly storms with a forward speed of 20 mph. The NHC also eliminated the 60 mph component of storms with a strong easterly direction for the same reason.

Storm tracks for each of the hypothetical storms were selected at 15-mile intervals to evaluate the potential storm surge over the entire study basin. Coney Island, New York was selected as the reference point, or zero point, for the analysis. All potential storm tracks which could impact the SLOSH basin were run for each selected hypothetical storm condition. A total of 533 hypothetical hurricanes were run for this model.

The SLOSH model has the capability of providing hurricane surge heights and wind velocities at a specific location relative to time during a simulated hurricane. The points, called Time/History points, are selected in areas where severe flooding is expected or where evacuation could be difficult. The points for the Connecticut study area were selected by officials of the State of Connecticut with assistance from the Corps and the National Hurricane Center. The Time History points will provide stillwater heights, windspeeds, and wind directions at 10-minute intervals for the duration of the hurricane. The Time/History points selected for the Connecticut study area are shown on Table 1.

MODEL OUTPUT

The model output for each of the storms will consist of a surface envelope of water which represents the maximum calculated surge heights at each grid square independent of time. These values are displayed on printouts on which the grid points are referenced by a system of coordinates. The model output also includes the Time/History point information for surge heights and wind data. The results of each model run are combined into Maximum Envelopes Of Water (MEOWs) by storm category, direction, forward speed or any other combination of parameters. Individual storm runs will be combined into MEOWs due to the uncertainty in predicting the storm track of an approaching hurricane. The Long Island Sound model will produce 52 MEOWs. These MEOWs will be further compiled by reviewing the similarities between the 52 original MEOWs in order to develop a product usable by the local emergency management agency.

TABLE 1

CONNECTICUT HURRICANE EVACUATION STUDY
LONG ISLAND SOUND SLOSH MODEL
CONNECTICUT TIME/HISTORY POINTS

Point	Program Name	Location	I Node	J Node
1	WATCHHILL	Watch Hill	72	55
2	GROTON	Groton	70	56
3	NEWLONDON	New London	70	57
4	NORWICH	Norwich	70	58
5	MILSTONE	Milstone	68	56
6	OLDSABRK	Old Saybrook	67	57
7	HADAM	Hadam	67	59
8	HAMONASET	Hammonasset	65	56
9	THMBLISL	Thimble Island	63	57
10	E. HAVEN	East Haven	61	58
11	NEWHAVEN	New Haven	60	59
12	W. HAVEN	West Haven	59	59
13	MILFORD	Milford	57	58
14	STRATFORD	Stratford	56	59
15	BRDGEPORT	Bridgeport	54	59
16	WESTPORT	Westport	51	59
17	NORWALK	Norwalk	49	59
18	STAMFORD	Stamford	46	59
19	SHPPANPT	Shippan Point	45	59
20	GRNCH. COC	Greenwich Cove	44	59
21	PRT. CHSTR	Point Chester	41	59

PRE-LANDFALL HAZARD TIMES

The Time/History output from the SLOSH model will be used to determine the pre-landfall hazard time. The pre-landfall hazard time is defined as the period evacuees will be exposed to hazardous winds and surge effects prior to the hurricane landfall. The pre-landfall hazard time begins at the arrival of gale-force winds (sustained 40 mile per hour) or when critical roadways or bridges are inundated from pre-landfall storm surge. The Time/History data will allow local officials to accurately estimate when an evacuation order should be given to avoid these conditions.

WAVE ANALYSIS

The SLOSH model will not provide data concerning the additional heights of waves generated on top of the still-water storm surge. Generally, waves do not significantly add to the inundated area and usually can be ignored except for locations with open coastline exposure or the shorelines of very large bays. Since near-shore wave phenomena under hurricane conditions is not well understood, it is assumed that for the open coast, the maximum theoretical wave heights occur near the time of landfall. Due to the presence of structures, dunes, or vegetation, the waves break and their energy dissipates within a few hundred yards of the coastline. For evacuation purposes, it is more important to calculate wave heights for less than gale force windspeeds. The rational here is to determine when critical areas may be inundated by wave action accompanying the stillwater surge and whether such inundation adds to the pre-landfall hazard time. Calculations of wave heights for potentially critical areas will be made using the shallow wave formulas contained in the Corps' Shore Protection Manuals.

Hurricane Evacuation Study
State of Connecticut

APPENDIX D

PROJECT SCHEDULE AND LOGIC NETWORK

Department of the Army
New England Division, Corps of Engineers
Waltham, Massachusetts
February 1988

TABLE D-1
CONNECTICUT HURRICANE EVACUATION STUDY
STUDY LOGIC NETWORK

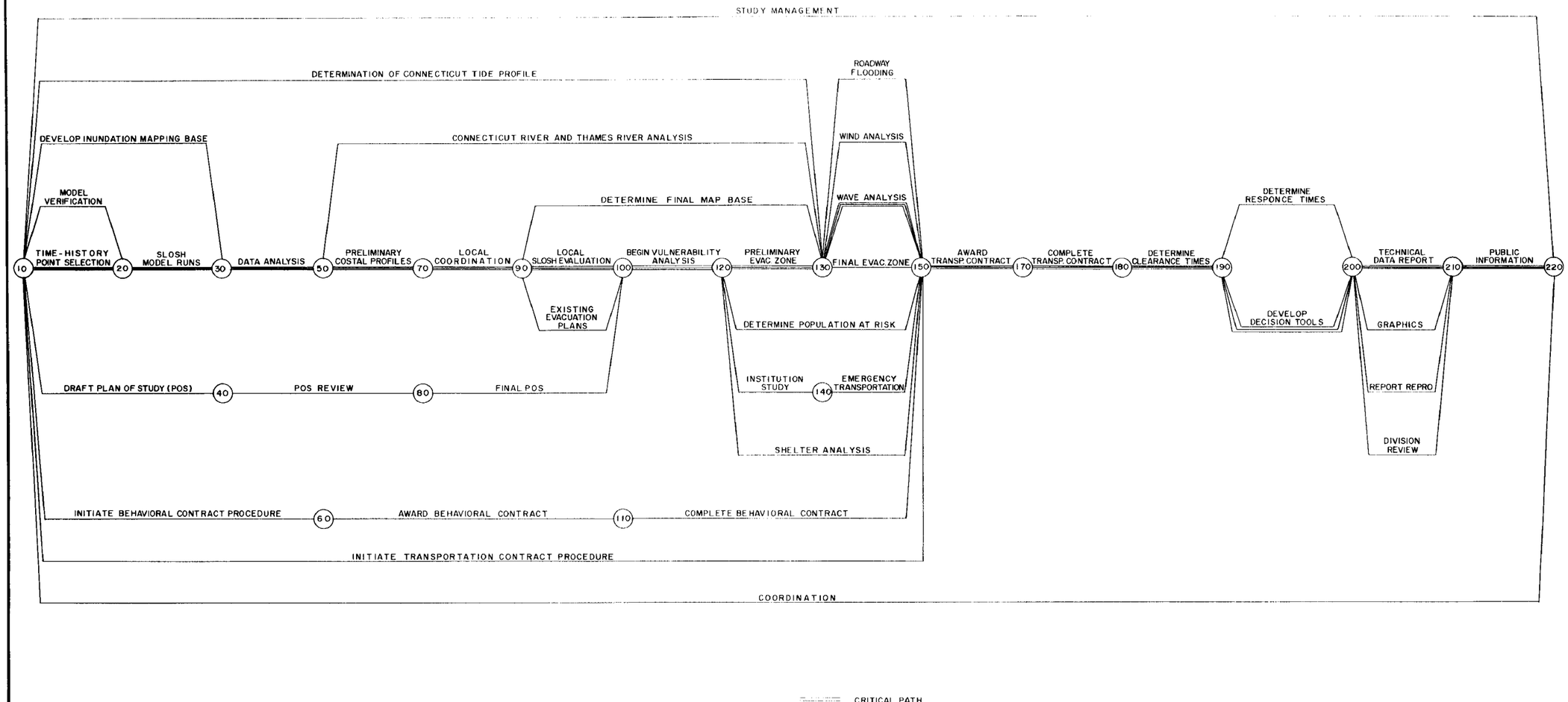
PROJECT TASK	I NODE	J NODE	DESCRIPTION
Time/History Points	10	20	Select critical locations along the Connecticut study area.
Model Verification	10	20	Final check of the SLOSH input data prior to the hurricane simulations.
Initial Inundation Maps	10	30	Develop an initial map base for preliminary evaluation of the SLOSH output.
SLOSH Model Runs	20	30	Run the Long Island Sound SLOSH model.
Draft Plan of Study (POS)	10	40	Develop the scope of work for the study to be referenced as the POS.
POS Review	40	80	Provide copies of the draft POS to FEMA and the state and local agencies for their review and comments.
Final POS	80	100	Evaluate comments and develop the final scope of the study.
Contract Behavioral Study	10	60	Initiate contracting procedures for the behavioral study.
Award Behavioral Contract	60	110	Award a contract for the behavioral study.
Complete Behavioral Study	110	150	Complete the behavioral study for the Connecticut study area.
SLOSH Data Analysis	30	50	Evaluate the results of the SLOSH model.
Initial Coastal Profiles	50	70	Develop preliminary profiles of the Connecticut coastal area from the SLOSH data.
Local SLOSH Review	70	90	Provide the SLOSH data to the State and local officials.
Local SLOSH Evaluation	90	100	Determine how the SLOSH data should be used in preparing evacuation plans.

TABLE D-1 (Continued)
CONNECTICUT HURRICANE EVACUATION STUDY
STUDY LOGIC NETWORK

PROJECT TASK	I NODE	J NODE	DESCRIPTION
Determine Final Map Base	90	130	Determine the final map base to be used in presenting the evacuation plans.
Existing Evacuation Plans	90	100	Collect existing evacuation plans from the State and local agencies.
Vulnerability Analysis	100	120	Begin the vulnerability phase of the study.
Connecticut Tide Profile	10	130	Update the Connecticut tide profile.
River Analysis	50	130	Evaluate the SLOSH data for the coastal river systems.
Initial Evacuation Zones	120	130	Develop preliminary evacuation zones.
Population At Risk	120	150	Determine the population at risk from a landfall hurricane.
Institution Analysis	120	140	Evaluate the special considerations which should be part of the evacuation scenario.
Emergency Transportation	140	150	Determine the emergency transportation needs which would be part of evacuation scenario.
Shelter Analysis	120	150	Determine the existing shelter capacity and its location and vulnerability.
Final Evacuation Zones	130	150	Develop the final evacuation zones.
Wind Analysis	130	150	Determine potential impacts to evacuation from gale force wind exposure.
Wave Analysis	130	150	Determine the impacts to evacuation from prelandfall wave action.
Roadway Flooding	130	150	Determine the impacts to evacuation from prelandfall flooding.

TABLE D-1 (Continued)
CONNECTICUT HURRICANE EVACUATION STUDY
STUDY LOGIC NETWORK

PROJECT TASK	I NODE	J NODE	DESCRIPTION
Contract Transportation Study	10	150	Initiate the Transportation Study contract procedures.
Award Transportation Study	150	170	Award the contract for the Connecticut study area transportation analysis.
Complete Transportation Study	170	180	Complete the transportation analysis.
Determine Clearance Times	180	190	Determine the time required to safely evacuate people from the evacuation zones.
Determine Response Time	190	200	Determine the total amount of time to complete an evacuation.
Develop Decision Tools	190	200	Develop decision tools to assist the State and locals respond to a hurricane threat.
Complete Technical Data Report	200	210	Complete a Technical Data Report outlining the study results and recommendations.
Public Information	210	220	Develop informational publications to assist in implementing the evacuation plans.



DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

HURRICANE EVACUATION STUDY

STATE OF CONNECTICUT

STUDY LOGIC NETWORK

NEW ENGLAND DIVISION — AUGUST 1987

FIGURE D - 1